Integrating Sustainability Grand Challenges and Experiential Learning into Engineering Curricula: Years 1 through 3

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Dr. Landis joined Clemson in June 2015 as the Thomas F. Hash '69 Endowed Chair in Sustainable Development. Previously, she was an Associate Professor at Arizona State University in the School of Sustainable Engineering and the Built Environment. She began her career as an Assistant Professor at the University of Pittsburgh, after having obtained her PhD in 2007 from the University of Illinois at Chicago under the supervision of Dr. Thomas L. Theis. She has developed a research program in sustainable engineering of bioproducts. Her research ranges from design of systems based on industrial ecology and byproduct synergies, life cycle and sustainability assessments of biopolymers and biofuels, and design and analysis of sustainable solutions for healthcare. Since 2007, she has lead seven federal research projects and collaborated on many more, totaling over $7M in research, with over $12M in collaborative research. At ASU, Dr. Landis continues to grow her research activities and collaborations to include multidisciplinary approaches to sustainable systems with over 60 peer-reviewed publications. Dr. Landis is dedicated to sustainability engineering education and outreach; she works with local high schools, after school programs, local nonprofit organizations, and museums to integrate sustainability and engineering into K-12 and undergraduate curricula.

Integrating Sustainability Grand Challenges and Experiential Learning into Engineering Curricula: Years 1 through 3

Today's complex global problems necessitate engineering solutions that not only consider sustainability but solutions founded on principles of sustainability to ensure the needs of today can be met tomorrow. Engineering educators face a difficult task of training students with both technical competencies and sustainability consciousness to tackle 21st century challenges. Two successful models for implementing sustainability tenets into engineering curricula have emerged in practice and in literature: course-based and modular-based models. Engineering programs implement the course-based model by establishing one to two distinct courses designed to address sustainability grand challenges in depth. Conversely, engineering programs implement the modular-based model by integrating sustainability grand challenges throughout a host of existing courses and weave student exposure throughout the curriculum via ready-made modules. The goal of this TUES 2 project is to evaluate the two models for implementing sustainability and to provide succinct recommendations and lessons learned for engineering programs tasked with integrating sustainability into their curricula. We are implementing and monitoring these two strategies in seven different engineering programs, including research universities: Arizona State University (located in Tempe, Arizona), University of Pittsburgh (located in Pittsburgh, Pennsylvania), and community colleges: Mesa Community College (located in Mesa, Arizona), Laney College (located in Oakland, California), and Community College of Allegheny County (located in Pittsburgh, Pennsylvania).

This paper summarizes the progress and accomplishments during years one through three of this four-year collaborative TUES 2 research project. We review the development of stand-alone sustainability courses and sustainability themed modules that employ experiential and active learning developed in Year 1. In addition, we review Year 2 dialogues and critical collaborations that led to the establishment of a faculty network to explore both the stand-alone course and modular methods. We also present results from ongoing research to assess student-learning outcomes related to sustainability in Year 3.

Background

Engineering students today are seeking careers that can make a difference. Engineering education needs to bring exciting topics and engaging methods into the classroom to motivate students toward goals that matter to them. Sustainable engineering offers a solution to these pressing challenges and appeals to today's youth by providing context for the role of a modern engineer in solving to 21st century problems. Additionally, sustainability topics in engineering curriculum can address many of the underlying factors facing diversity and retention of students that otherwise leave STEM majors due to lack of engagement and/or motivation[1]. Despite growing interest, many universities struggle with how to best update engineering curriculum and overcome barriers to adequately merge and teach new concepts, like sustainability, in an already full curriculum[2,3].

Two methods for integrating sustainability into engineering curriculum predominate the literature; these methods have been generalized as a stand-alone course-based method and a modular-based method. In the stand-alone course-based method, an engineering program establishes one or two distinct, stand-alone courses into the students' curriculum that focus on sustainability in engineering. In the modular-based method, engineering programs integrate sustainability throughout a host of existing courses by threading individual sets of course skills together in an effort to reach higher levels of intellectual behavior via interdisciplinary concept connection[4]. Modules can be designed to fit into one lecture or over a series of lectures, connecting multiple engineering themes. Modules typically include everything an instructor needs for implementation: a summary of learning objectives and module activities, lecture slides and notes, recommended readings, and an assignment for students. In the proposed project, our modules will also include instructions, grand challenges discussion questions, an example you-tube video for conducting the experiential learning activity, and an assessment of student learning and module effectiveness.

Two large programs in the US have compiled resources for integrating sustainability into engineering curriculum based on the stand-alone course- and modular-based methods. The Center for Sustainable Engineering (CSE) has created a peer-reviewed repository for stand-alone sustainable engineering courses, accessible at: http://www.csengin.org[5,6]. The UT-Arlington Engineering Sustainable Engineers (ESE) program has taken a modular approach and implemented 11 non-active learning sustainability modules in Civil Engineering (CE), Industrial Engineering (IE), and Mechanical Engineering (ME), accessible at: http://www.uta.edu/ce/ese/index.htm[7,8]. In this TUES 2 research project we explore both methods for integrating sustainability into engineering curriculum in conjunction with literature best practices of active and experiential learning pedagogies to engage students in direct experiences with course/module content and inspire life-long learning of sustainability[9,10].

Development of Educational Materials (Year 1)

The TUES 2 research team focused on development of educational materials during Year 1 (Y1) of this four-year collaborative research project. This resulted in the development of three stand-alone sustainable engineering courses, Green Building Design and Construction, Life Cycle Assessment, and Sustainability Topics in Engineering, which can be adapted for different levels of undergraduate engineering curriculum. During Y1 we also created ten new modules, Module United Nations, Life Cycle Thinking, Sustainable Metrics, Energy-Supply, Demand and Transmission, Energy-Renewables, Packaging, Technology Evolution, Sustainable Waste Management, Carbon and Water Footprinting, and Tragedy of the Commons, to compliment our existing modules on topics of Green Washing and Labeling and Energy Auditing[11]. The courses and modules will be made available on our website, stemed.engineerng.asu.edu. While all of the modules have been implemented more than once, the Energy Auditing and Sustainable Metrics modules remain amongst our most requested and widely-implemented across both engineering and science curriculums but also sustainability and teacher's college[12,13].

Establishment of Faculty Network (Year 2)

During Year 2 (Y2) focused on establishment of faculty network to test educational materials developed during Y1. The core TUES 2 research team has engaged several faculty outside of their institutions, including faculty at Laney College, Community College of Allegheny County, and Mesa Community College[14]. During Y2 the TUES 2 project expanded its original boundaries to Chandler-Gilbert Community College (located in Chandler, Arizona) due to the movement of one collaborator[15]. The establishment of our faculty network and deployment of modules and courses within engineering courses and curriculum six institutions has impacted the education of more than 2,000 students in the first three years of this project.

Assessment of Student Learning (Year 3)

The research team focused on assessment of student learning, in the context of sustainable engineering during Year 3 (Y3) of this four-year project. We present current assessment methods for understanding student-learning outcomes related to sustainability in addition to a novel rubric, developed by the research team, to compliment gaps in assessment methodologies.

Strategies for evaluating student-learning outcomes for sustainability include assessing knowledge of sustainable engineering principles via critical and holistic thinking in accordance with American Society for Civil Engineering (ASCE) Body of Knowledge 2 (BOK2) and Bloom's taxonomy, quantifying student inclusion of sustainable engineering topics, whether or not a student links three pillars of sustainability (environmental, economic, social), and utilizing instructor-created rubrics on course content or available assessment tools such as the Sustainability in Higher Education Assessment Rubric (SHEAR)[16-22]. Despite potential uses, these strategies for assessing sustainability in higher education lack details indicative of interdisciplinary knowledge transfer necessary for learning sustainability. There is a need for stakeholders to pioneer a universal assessment tool or, at the very least, agree on a minimal set of metrics to assess advancements in incorporating sustainability in higher education and evaluating engineering students' sustainability knowledge across a curriculum[23].

We present a succinct version of our rubric in Table 1. This rubric builds on best practices in the literature for assessing student application on sustainability topics in engineering and includes questions on the cognitive levels achieved, linkage between sustainability pillars (environmental, economic, social), quantitative versus qualitative incorporation of sustainability, and the sustainability topics students may have been exposed to during their undergraduate engineering career[18,21]. The TUES 2 research team is in the process of publishing results from the application of the expanded version of this rubric on students' senior design capstone and sustainable engineering course projects. The results will be used to inform student learning *across a curriculum* that integrates sustainability via stand-alone course, module, or blended methods.

Table 1. Rubric for assessing student application of sustainability topics in engineering

Criteria		Possible Score
1. Cognitive levels of sustainability topics incorporated[21]		1. Knowledge (recall of information)
		2. Comprehension (demonstrating, discussing)
		3. Application (applying knowledge, designing, experimenting)
		4. Analysis (recognizing trends and patterns)
		5. Synthesis (using old concepts to create new ideas)
		6. Evaluation (assessing theories and outcomes)
2. Sustainability Links[18]	No Evidence	No Evidence
	Concepts	Societal
		Economic
		Environmental
	Crosslinks	Societal-Economic
		Economic-Environmental
		Environmental-Societal
	Interdependent	Societal-Economic-Environmental
3. Quantitative or qualitative incorporation of sustainability?	Environmental	Quantitative Qualitative
	Economic	
	Social	
4. Sustainability Topics (explicit or implicit inclusion)	Sustainable Agriculture, Sustainable Land Use, Industrial Ecology, Corporate Sustainability, Climate Change, Renewable Energy, Green Buildings, Sustainability Infrastructure, Green Construction, LCA (Life Cycle Assessment), Material Flow Analysis, Natural Resource Depletion (or Scarcity), Pollution Prevention, Design for the Environment, Green Chemistry, Environmental Justice, Embedded/Virtual Water Use, Anthropogenic Environmental Impacts, Sustainability Rating Schemes (e.g. LEED), Resilience, Urbanization/urban sprawl, Sustainability economics, Governance for sustainability, Sustainable Innovation, Sustainability Ethics, Other 1- recycling, Other 2- water reuse, Other 3- energy reduction, Other 4- Urban heat island effect, Other 5- alternative transportation, Other 6- consider needs of people/ stakeholder engagement, None	

Conclusion & Future Direction

Ongoing integration of both stand-alone courses and modules have shown to be necessary for sustainability to reach 'appropriate' levels of mastery in engineering education, from a practical implementation perspective, as well as student cognition level.

In year 4 of this TUES 2 project we will continue to assess student learning outcomes related to sustainability for students participating in both the stand-alone course and modular-based methods. In addition, we will evaluate program outcomes with particular focus on faculty barriers to implementing sustainability within their engineering courses and instructional barriers for curricular change. Ultimately, we aim to develop succinct recommendations regarding best practices for universities integrating sustainability into engineering curricula via stand-alone course, modular, or blended methods.

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